# EVALUATION OF SMOS SOIL MOISTURE BASED ON RAINFALL VARIABILITY OVER SEMI-ARID TRACT OF INDIA

Rainfall plays a vital role in both agriculture and environmental disasters, mainly, floods and droughts. Therefore, a global study of spatial distribution of rainfall will help in better understanding of solutions to these environmental problems. Surface soil moisture is a correlation parameter that gets highly affected by rain occurrence and in addition to this, Elfatih (1998) showed a positive correlation between surface soil moisture and rainfall. Thus, this motivates to evaluate surface soil moisture estimates with rainfall. Theoretically and experimentally, the best proven frequency for soil moisture estimation is 1.4 GHz (L-Band). On 2nd Nov., 2009, ESA launched SMOS mission, for estimation of soil moisture and ocean salinity through L-band observations. The accuracy in soil moisture retrieval, as claimed by SMOS mission, is 4% as given in Kerr *et al.* (2010). There are some works like Tomer *et al.* (2010) going on in India for validation of SMOS soil moisture product.

In this paper, spatial and temporal variability of surface soil moisture maps retrieved from SMOS with 4% accuracy, are correlated with spatial and temporal variability of rainfall, over Rajasthan, Madhya Pradesh and Andhra Pradesh in India and a good correlation is observed between these two data sets.

2. The instrument operating onboard SMOS satellite is a Microwave Imaging Radiometer with Aperture Synthesis (MIRAS). The details of MIRAS are given in McMullan *et al.* (2008). It is a passive microwave sensor that measures the strength of microwave emission in terms of brightness temperature, as defined in Ulaby *et al.* (1981). It has a sun synchronous orbit, having the instrument tilt angle of 32.5 degree and 0600 hrs local ascending at equatorial plane. Its radiometric accuracy in brightness temperature is 1.8 K (at 180 K) and 2.2 K (at 220 K). It provides brightness temperatures from 0-55 degree incident angle, over 1000 km swath, with 30-50 km spatial resolution at 1.4 GHz. Thus, it gives a single integrated value of brightness temperature over a ~1600 km^2 area. This multi-angular brightness temperature values are, then, used in inversion radiative transfer models to retrieve surface soil moisture maps with an spatial resolution of ~20 km. Although, as explained in Kerr *et al.* (2012) and SMOS Algorithm Theoretical Basis Document Kerr *et al.* (2010), the radiometric resolution of SMOS at 1.4 GHz ~40 km, but due to its multi-angular observations, it processes the data to give soil moisture maps at ~20km spatial resolution. Snapshots
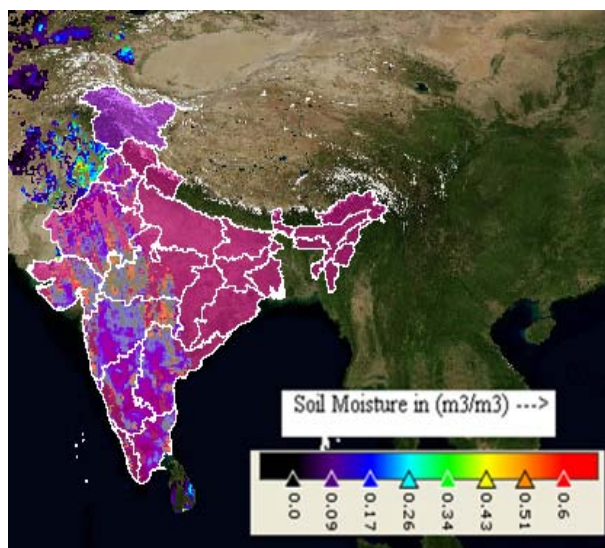
Fig. 1(a).   SMOS pass on 23rd August, 2011, here warmer colours (Reddish) indicates high soil moisture values while colder ones (Bluish) indicate lower soil moisture values
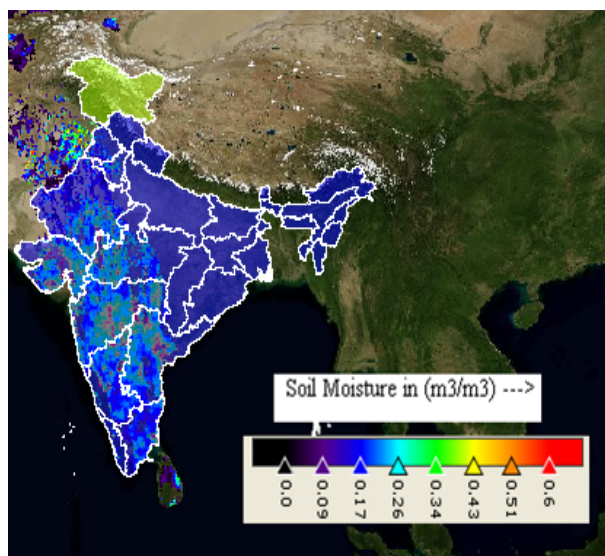
Fig. 1(b).   SMOS pass on 10th September, 2011, here warmer colours (Reddish) indicates high soil moisture values while colder ones (Bluish) indicate lower soil moisture values

of these SMOS soil moisture maps are shown in Figs. 1(a&b). The temporal resolution of this data is around three days maximum. In spite of, acceptable spatial and temporal resolution of SMOS data, Radio Frequency Interferences (RFIs) at 1.4 GHz over north and north-western parts of India is a serious concern, as these RFIs dilute the SMOS soil moisture product. Details of these RFI maps are available online at http://www.cesbio.ups-tlse.fr/SMOS_blog/.

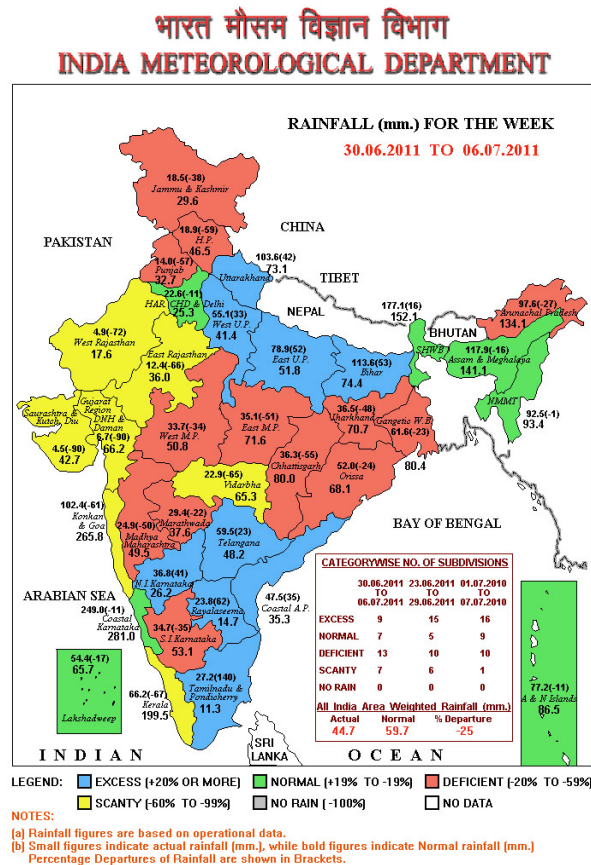It must be noted that for each state of India, IMD rainfall maps are giving a single value of rainfall averaged

Fig. 2. Weekly average rainfall departure maps of the IMD during 30th June - 6th July, 2011

Fig. 3(a). Spatial distribution of rainfall over Rajasthan, Madhya Pradesh and Andhra Pradesh during 18-24 August, 2011

Fig. 3(b). Spatial distribution of rainfall over Rajasthan, Madhya Pradesh and Andhra Pradesh during 8-14 September, 2011

over a week as shown in Fig. 2. Thus, for each state, SMOS soil moisture is also averaged, both spatially and temporally over a week for easy comparison with actual rainfall values obtained from IMD maps.

Rainfall departure maps are freely available on India Meteorological Department website at http://www. imd. gov.in. One of the maps is shown in Fig. 2. These maps indicate the departure of actual rain from the normal. The values shown on these maps are average values for a week. In these, small numerical values indicate actual rainfall in mm while bold numerical values indicate normal or predicted rainfall in mm and the values shown in brackets indicate the percentage departure of actual rain from the normal. Actual rainfall values from these maps were thereafter utilized to generate spatial distribution of weekly rainfall over three states namely, Rajasthan, Madhya Pradesh and Andhra Pradesh, for selected six weeks during the month of July, August and September, 2011. Figs. 3(a&b) shows such two maps, for the month of August and September 2011 with contrasting seasons, dark blue shade indicates the state that had minimum weekly rain among the three states, red shade indicates the
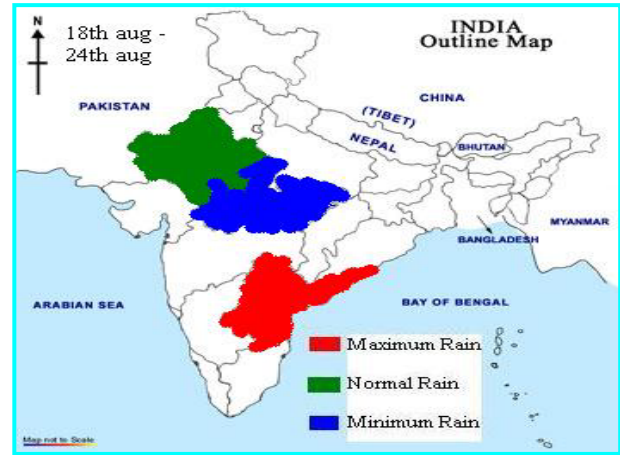
state over which maximum weekly rain occurred, and green shade indicates the state over which there was intermediate amount of rainfall.

In addition to this, average monthly rainfall data of IMD at district level, available online at http://www. imd.gov. in/section/hydro/distrainfall/districtrain.html, are also compared district- wise with the SMOS soil moisture averaged over a month. Here, spatial resolution of data sets is increased at the cost of their temporal resolution.

3. The methodology adopted for the work is shown in Fig. 4. Two comparisons are made. In first comparison, three states, namely, Rajasthan, Madhya Pradesh and Andhra Pradesh are selected. Then, average soil moisture over these states are evaluated from SMOS

TABLE 1

Average SMOS soil moisture in volumetric fraction for six selected weeks during the month of July, August and September, 2011

S. No.	Weeks of Year 2011	Rajasthan (Rain in mm)	Rajasthan (Soil Moisture in m^3/m^3)	Madhya Pradesh (Rain in mm)	Madhya Pradesh (Soil Moisture m^3/m^3)	Andhra Pradesh (Rain in mm)	Andhra Pradesh (Soil Moisture in m^3/m^3)
1.	30 June - 6 July	8.65	0.09	34.40	0.20	41.65	0.22
2.	21 July - 27 July	24.95	0.16	111.05	0.39	49.95	0.24
3.	4 August - 10 August	83.50	0.22	127.40	0.36	16.65	0.20
4.	18 August - 24 August	32.80	0.24	30.10	0.22	88.30	0.27
5.	8 September - 14 September	43.90	0.23	62.45	0.33	22.65	0.21
6.	22 September - 28 September	0.70	0.16	17.15	0.21	4.00	0.17

soil moisture data for selected six weeks during the month of July, August and September, 2011. These weeks are 30th June-6th July, 21st July-27th July, 4th August-10th August, 18th August-24th August, 8th September-14th September and 22nd September-28th September, 2011. The average soil moisture values, evaluated from SMOS data are tabulated in Table 1 for selected six weeks. After this, average rainfall values are evaluated from IMD rainfall maps, one of such map is given in Fig. 2 and tabulated in same Table 1 for these weeks.

Secondly, district-wise monthly rainfall data of IMD are also compared with the SMOS soil moisture, averaged during a complete month, over each district of Rajasthan, Madhya Pradesh and Andhra Pradesh. In this comparison, temporal resolution of data is compromised for higher spatial resolution of data.

4.   Table 1 shows the evaluated average soil moisture values over Rajasthan, Madhya Pradesh and Andhra Pradesh from SMOS data for selected six weeks and their corresponding values of rainfall over these states. From Table 1, it can be observed that spatial variability of soil moisture correlates with IMD rainfall data for all selected six weeks. This shows a positive feedback of rainfall on surface soil moisture. Fig. 5 shows the same with correlation factor of 0.73. In addition to this, the temporal variability of surface soil moisture also correlates well with IMD rainfall data over Rajasthan, Madhya Pradesh and Andhra Pradesh, except the temporal variability of surface soil moisture over Madhya Pradesh for the selected six weeks.

However, when a graph is plotted in Fig. 6 by excluding the anomalous data of the week 4-10 August, 2011, the correlation factor increased to 0.77. From Table 1, it can be seen that such anomalies are very less and there is a good correlation of spatial and temporal variability of surface soil moisture with IMD rainfall data.

Similar results are also observed, when district-wise IMD rainfall data are compared with SMOS Soil Moisture, during the month of July, August and September, 2011 over Rajasthan, Madhya Pradesh and Andhra Pradesh. It must be noted that district-wise IMD rainfall data shows average rainfall over a month in a particular district of a state. Thus, SMOS soil moisture at district level is also averaged over a month and compared with these IMD data. Fig. 7 shows the comparison of district-wise monthly IMD rainfall data with SMOS soil moisture for three months, *i.e.*, July, August, September 2011 over all the districts of Rajasthan, Madhya Pradesh and Andhra Pradesh at which both IMD & SMOS data are available. Here also, a direct correlation is observed between these two data sets, with correlation factor of 0.243. However, when maximum outlier (or anomalous data sets) that are observed in data sets of September, 2011, are removed, then the correlation factor increased from 0.243 to 0.508 as shown in Fig. 8.

There are various reasons for these anomalous data sets. This may be due to the different amount of water retained in the surface soil after the rainfall. SMOS has sun-synchronous orbit with local timing of 0600 hrs equatorial ascending and 1800 hrs equatorial descending. Thus, soil moisture retrieved from SMOS satellite is the moisture that was present during the SMOS pass on 0600 hrs IST in the morning or 1800 hrs IST in the evening. Thus, if rainfall occurred around 1600-1700 hrs IST or 0400-0500 hrs IST then, the moisture observed by satellite will be more as compared to the soil moisture observed by the satellite when same amount of rainfall, over same region, would have taken place around 1000-1100 hrs IST or 2200-2300 hrs IST. Secondly, the accuracy of SMOS soil moisture is 4%. Thus, this can also be one of the reasons for the anomalous data sets.
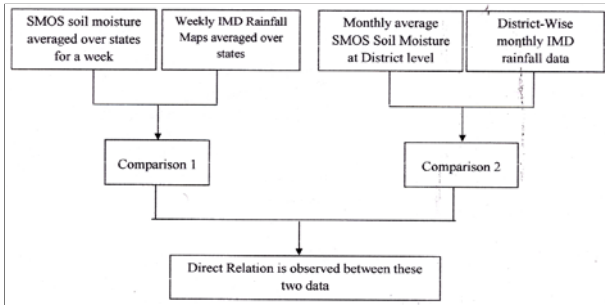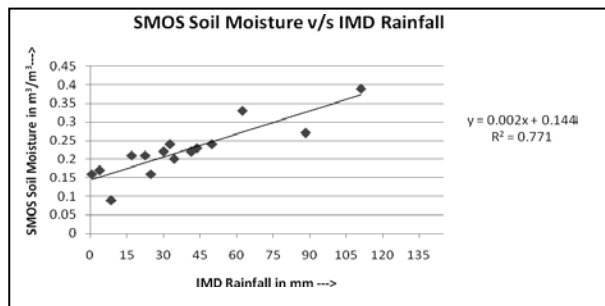
Fig. 4. Methodology for correlating average SMOS soil moisture values with IMD rainfall data.
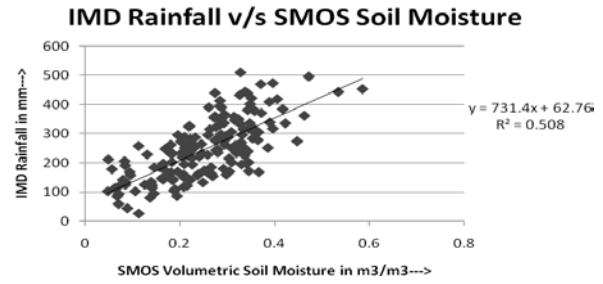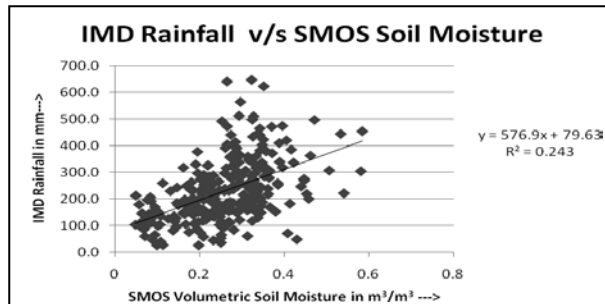

Fig. 8. Comparison of SMOS Soil Moisture with District-Wise IMD rainfall data during July & August 2011
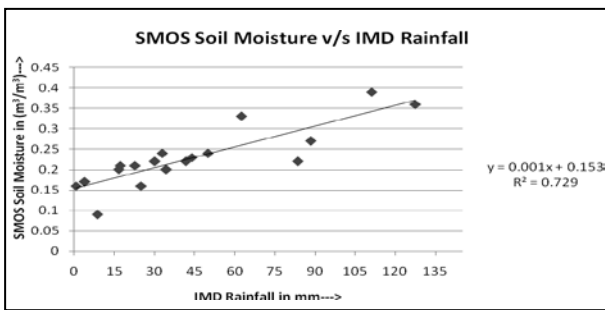
Fig. 5. Correlation between SMOS soil moisture with the IMD rainfall at state level

Finally, from Figs. 5, 6, 7, & 8, it can be concluded that SMOS soil moisture shows a good correlation with IMD rainfall data. When anomalous data sets are removed, then the correlation factor increases to a more satisfactory level as shown in Figs 6 & 8.

5. From this study, it can be concluded that there is a direct relationship between IMD rainfall data and surface soil moisture retrieved from SMOS. For maximum data sets, the value of correlation coefficient 'r' observed is above 0.5. Thus, it indicates that the surface soil moisture variability observed by passive microwave sensors correlates well with the rainfall variability. Thus, only for arid and semi-arid regions, which are mainly rain-fed areas, rainfall variability can be treated as evaluation tool for soil moisture estimates from SMOS due to lack of availability of high-density soil moisture measurements which are representative of 1600 square km or more. However, quantification of soil moisture from rainfall data and vice versa will require more *in-situ* and satellite data analysis, for generating a model that can relate rainfall with the soil moisture maps retrieved from microwave sensors onboard satellites.

Fig. 6. Correlation between SMOS soil moisture with the IMD rainfall at state level

The surface soil moisture retained by soil depends on various other factors like vegetation, soil texture, solar radiation etc. Moreover, Elfatih (1998) showed that land atmosphere energy fluxes and evapo-transpiration in environment is governed by surface soil moisture conditions which in turn decides the break and active rainfall events. Thus, further analysis can be done to link together all the factors affecting the surface soil moisture conditions.

Fig. 7. Comparison of SMOS Soil Moisture with District-Wise IMD rainfall data during July, August and September 2011

Reference

Elfatih, A. B., 1998, "A Soil Moisture-feedback mechanism", *Water Resources Research*, **34**, 765-776.

Kerr, Y. H., Waldteufel, P., Richaume, P., Davenport, I., Ferrazzoli, P. and Wigneron, J. P., 2010, "SMOS Level 2 Processor Soil Moisture ATBD, SM-ESL (CBSA)", *Toulouse SO-TN-ESL-SM-GS-0001*

Kerr, Y. H., Waldteufel, P., Wigneron, J. P., Delwart, S., Cabot, F., Boutin, J., Escoriihuela, M. J., Font, J., Reul, N., Gruhier, C., Juglea, S. E., Drinkwater, M. R., Hahe, A., Martin Neira, M. and Mecklenburg, S., 2010, "The SMOS Mission: New Tool for Monitoring Key Elements of the Global Water Cycle", *Proc. IEEE Trans. Geosci. Rem Sens*, **98**, 666-687.

Kerr, Y. H., Wigneron, J. P. and Mahmoodi, A., 2012, "The SMOS Soil Moisture Retrieval Algorithm", *IEEE Trans. Geosci. Rem Sens*, **50**, 5.

McMullan, K., Brown, M., Martín-Neira, M., Rits, W., Martí, J. and Lemanczyk, J., 2008, "SMOS: The payload", *IEEE Trans. Geosci. Rem Sens.*, **46**, 594-605.

Online link- http://www.imd.gov.in

Online link - http://www.cesbio.ups-tlse.fr/SMOS_blog/

Online link - http://www.imd.gov.in/section/hydro/ distrainfall/ districtrain.html

Tomer, S. K., Bitar, A. Al., Kerr, Y., Sekhar, M., Bandyopadhyay, S. and Mohan, S., 2010, "Validation of SMOS data over AMBHAS, India and SCAN, U. S.", available online at - http://www.ambhas.com/pre.php.

Ulaby F. T., Moore R. K. and Fung A. K., 1981, "Microwave Remote Sensing - Active and Passive vol. 1"Norwood, USA: Artech House.

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